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Colored Light and Brain and Muscle Oxygenation

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Abstract Colored light is applied in medicine in the treatment of various diseases. The aim of this study was to investigate potential effects of exposure to blue and red light on brain and muscle blood volume ([tHb]) and tissue oxygenation (StO_2) measured by non-invasive near-infrared spectrophotometry (NIRS). Ten healthy volunteers were included in a randomized crossover study. Blue light exposure leads to decreased oxygen consumption in the brain and the skeletal muscle. Blue and red light have significantly different effects on [tHb] and StO_2.

1. Introduction

Light of different colors (CL) is applied for various medical conditions to improve the physical, emotional or mental state of patients. Examples are the use of blue light in the treatment of the neonatal jaundice [1], a phenomenon due to the immature liver function of newborns, the application of red [2] and UV light in dermatology (physical level), and the use of bright white light to treat seasonal affective disorders [3] (emotional or mental level). It is known that blue light is strongly absorbed by the skin, suppresses melatonin production and is generally associated with coldness. In contrast, red light penetrates tissue relatively deeply and is associated with warmth. However, little is known about the effects of CL on hemodynamics and tissue oxygenation.

We therefore investigated potential effects of blue and red light, being the two main colors used in medical treatments, on blood volume and tissue oxygenation in the brain and skeletal leg muscle using near-infrared spectrophotometry (NIRS).

2. Materials and methods

Ten healthy volunteers (5 male, 5 female; mean age 27, range 23-44 years) were measured during blue and red light exposure. Light was generated using thermal white light sources (60W, OSRAM Inc., Germany) and color filters (Lee Inc., Germany). During exposure phases the CL was projected onto a white wall. The subjects were seated in a comfortable chair facing the wall. Subjects were asked to keep their eyes open throughout the entire measurement. Otherwise the room was completely dark and instruments were shielded in order to avoid ambient light.

All subjects were measured twice on different days, exposed to blue or red light in a randomized crossover protocol. The protocol consisted of 8 min baseline (darkness), 10 min CL (blue or red) exposure, followed by 16 min recovery (darkness). Blood volume, i.e. total hemoglobin concentration ([tHb] in µM) and tissue oxygen saturation (StO_2 in %) were measured with a Hamamatsu NIRO 300 instrument. One sensor was attached to the forehead and the other to the lateral calf muscle. Using a paired t-test the last 5 min of the baseline were compared to the first and last 5 min of the CL exposure, and to 3 periods of 5 min of the recovery. Blue and red exposures were compared by a linear mixed effects (LME) model (R statistical software).

3. Results

In the leg, tHb concentration increased significantly during and after exposure by up to (mean ± SEM) 1.08±0.19µM ($p=0.0002$) for blue and 1.52±0.33µM $p=0.0013$) for red light (Fig. 1). Although StO_2 did not change significantly compared to baseline, StO_2 was significantly higher under blue than under red light conditions (Table 1).

In the brain StO_2 increased significantly during blue exposure by 0.51±0.21% ($p=0.0367$), with a maximum shortly after exposure 0.98±0.40% ($p=0.0324$) while tHb concentration did not change significantly (Fig 2.). During red exposure StO_2 changed a little but not significantly. The increase in StO_2 during exposure to blue light was significantly different from red light (Table 1).

Table 1: Results of a linear mixed-effects statistical analysis to compare changes during and after exposure to blue light to changes during and after exposure to red light.

Parameter	Location	p-value blue vs red	
StO_2	Brain	**0.001**	
	Muscle	**0.006**	
tHb	Brain	0.609	
	Muscle	0.102	

4. Discussion and Conclusion

In the leg, the [tHb] increased continuously in the course of time and independently of the color, which most probably indicates venous pooling of the blood in the calf muscle during the measurement. StO_2 remained relatively constant, but was significantly different between blue and red light exposure (Table 1). This may indicate a decreased oxygen consumption due to exposure to blue light.

In the brain, the [tHb] remained relatively constant, which may indicate that blood volume and blood flow did not change due to exposure to light of different colors. However, the simultaneous significant increase in StO_2 during exposure to blue light indicates that oxygen consumption in the brain decreased. This is particularly interesting because blue light is known to induce alertness, an effect that might be expected to be related to increased oxygen consumption. Clearly, blue and red light have different effects on hemodynamics and tissue oxygenation.

The underlying reasons for the observed phenomena are not yet clear. Aspects that need to be considered in future research are the distribution of cones and rods in the retina, the sensitivity of the eye to different colors, and exposure to colored light in addition to red and blue.

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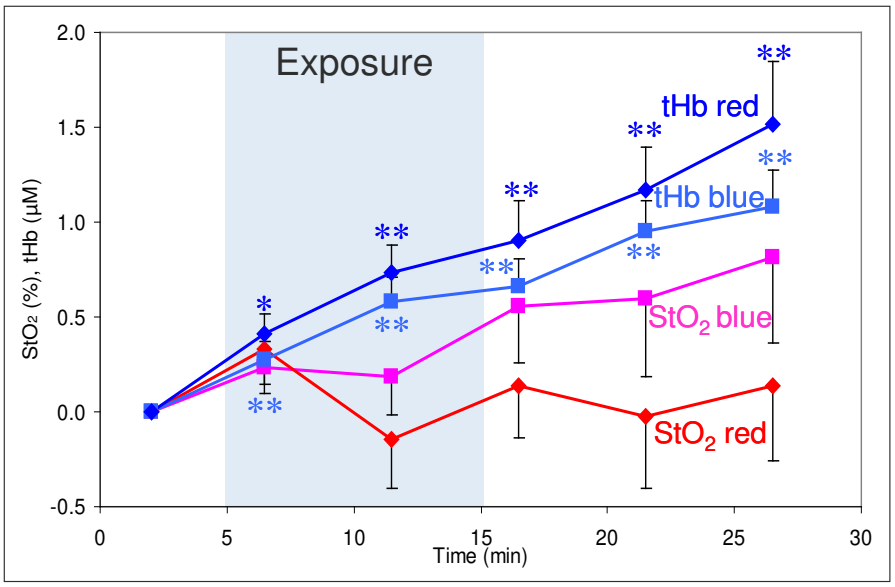

Fig. 1. Changes in muscle blood volume (tHb) and tissue oxygenation (StO_2) during exposure to blue and red light. tHb increases continuously, while StO_2 remains more of less constant. (*) Indicates a significant ($p<0.05$) difference between the period before exposure (0-5min) compared to another period. (**) Indicates high significance ($p<0.001$). The shaded area indicates the exposure period to colored light.

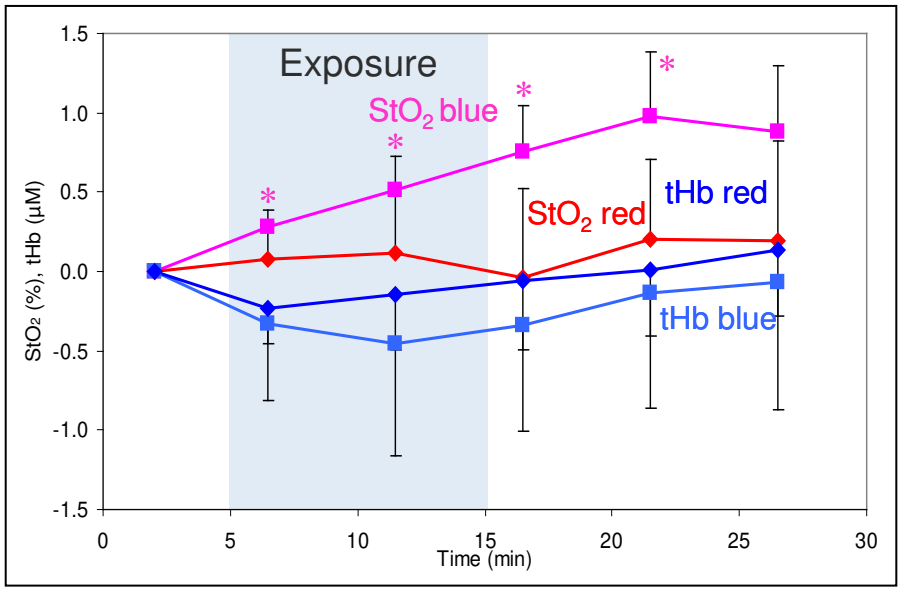

Fig. 2. Changes in brain blood volume (tHb) and tissue oxygenation (StO_2) during exposure to blue and red light. tHb remains constant, while StO_2 increases significantly during and after exposure to blue light. (*) Indicates a significant ($p<0.05$) difference between the period before exposure (0-5min) compared to another period. The shaded area indicates the exposure period to colored light.